June 19, 2006

DECLARATION

The undersigned, Jan McLin Clayberg, having an office at 5316 Little Falls Road, Arlington, VA 22207-1522, hereby states that she is well acquainted with both the English and German languages and that the attached is a true translation to the best of her knowledge and ability of the International Patent Application PCT/EP 2004/053466 of SHENDI, A., entitled "STATOR FOR AN ELECTRICAL MACHINE".

The undersigned further declares that the above statement is true; and further, that this statement was made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or document or any patent resulting therefrom.

Jan McLin Clayberg

STATOR FOR AN ELECTRICAL MACHINE

Prior Art

The invention relates to a stator for an electrical machine as generically defined by the preamble to the independent claim.

From published German Patent Application WO 01/54254 A1, a stator for an electrical machine is known which is made by what is known as the flat-packet technique. The flat- packet technique can be described by saying that at first, individual striplike laminations are furnished, which are packeted into a so-called flat packet. To that end, the laminations are arranged in such a way that they are stacked on one another congruently. This forms an approximately block-shaped, essentially flat stator iron, which on one side in comblike fashion has the electromagnetically operative slots and teeth, which once the stator has been completed are provided for the interaction with a rotor. Into this comblike, block-shaped stator iron, a separately prepared, as a rule three-phase winding is inserted, so that initially, either all the coil sides are located in the slots, or the great majority of the coil sides, as disclosed in the reference cited. This semifinished product comprising the stator iron with the winding is then bent into a round shape in an apparatus in such a way that a circular-annular, annular-cylindrical stator is created. Optionally existing winding transitions, which upon insertion of the winding into the stator iron are at first not located in slots, are introduced into the corresponding slots in the course of the bending into the round shape. After the bending into the round shape, two face ends oriented in the peripheral direction are located directly opposite one another. These face ends can then be joined together, for instance by a welding operation.

In the course of development work for this stator and the associated electrical machine, it has been demonstrated that by making various provisions, in particular dimensional ratios of such a stator or stator iron, very different results are attained.

Advantages of the Invention

The stator according to the invention having the characteristics of the main claim has the advantage that because of the ratio A formed from the slot area and the end face area and amounting to between 0.4 and 0.8, a first approximation for an optimal design of a stator in accordance with the intended production process is indicated.

In a second approximation, it is provided that the ratio A is between 0.4 and 0.7. This second, narrower ratio provides a marked improvement in terms of dimensioning, so that with this second range of the ratio, with little consumption of material, on the one hand the current yield with respect to the mass of the stator is improved, and on the other, the bending resistance of the stator or the stator iron is in a range which permits both bending of the flat stator into the round shape and the dimensional stability of the round stator.

Drawings

In the drawings, exemplary embodiments of a stator of the invention are shown.

Fig. 1 shows a flat packet without a winding;

Fig. 2 shows a flat packet with an inserted three-phase winding;

Fig. 3 shows the flat packet with the winding from Fig. 2, after the joint bending of the winding and iron packet into a round shape;

Fig. 4 shows a detail in elevation view of an end face of a stator iron for the sake of clearly showing the slot area and end face;

Fig. 5 shows a detail of a cross section through a slot, provided with conductors, to illustrate the conductor cross section;

Fig. 6a shows a first "current graph";

Fig. 6b shows a second "current graph";

Fig. 7 shows a detail in elevation view of two inner teeth with the associated slot;

Fig. 8 is a three-dimensional graph, showing the output current of a motor vehicle generator as a function of two different length ratios during engine idling, corresponding to approximately 1800 rpm of the generator rotor.

Description

Fig. 1 shows a flat or substantially flat stator iron 10, which has been made into a packet comprising a defined number of individual laminations 13. The laminations 13 are stacked one above the other in the so-called axial direction a, so that they are located one above the other congruently. A yoke 16 extends in the so-called circumferential direction p, which later extends annularly in the completed stator. From the yoke 16, so-called inner teeth 19 extend in the radial direction r and later, in the completed stator, they extend radially inward. The stator iron 10 has two face ends 22 in the circumferential direction p which rest directly against one another after the stator iron 10 has been bent into a round shape. If the stator iron 10 is equipped with thirty-six slots 25, for example, then this stator iron 10 has a total of thirty-five complete inner teeth 19 and one half-inner tooth 27 on each of the face ends 22. In the stator iron 10 or stator bent into the round shape, the two half-inner teeth 27 then contacting one another add up to one complete inner tooth. In a stator iron 10 with forty-eight slots 25, the stator iron 10 analogously has forty-seven complete inner teeth 19 and again two half-inner teeth 27.

Fig. 2 shows the stator iron 10 of Fig. 1, into whose slots 25 a stator winding 30 is inserted. If the stator is intended for a rotary current generator, then the stator winding 30 is embodied as a three-phase winding. The stator winding 30 is initially manufactured separately from the manufacture of the stator iron 10. The stator winding 30 can then, as one alternative, comprise individual phases which

are each introduced separately into the slots 25 of the stator iron 10. However, as another alternative, the stator winding 30 may also, as in the prior art cited at the outset, be manufactured such that the three phases of the stator winding 30 are prepared in the form of a practically one- piece stator winding 30. This practically one-piece stator winding 30 is then inserted in its entirety and in one step into the slots 25 of the stator iron 10.

Once the stator winding 30 has been placed in the stator iron 10, as described above, the semifinished product comprising these two parts is bent into a round shape, in such a way that the inner teeth 19 and half-inner teeth 27 extend radially inward and thus the yoke 16 surrounds the inner teeth 19 and 27. The slots 25 are then intrinsically open radially inward; see also Fig. 3. In Fig. 3, an abutment point 33 can be clearly seen, where the aforementioned two half-inner teeth 27 contact one another directly. The stator iron 10, or the stator 36 thus created, now has an essentially annular-cylindrical shape. This annular- cylindrical shape has a cylinder axis which can be inscribed in the interior of the stator 36. This cylinder axis extends in the above-described axial direction and thus in the stacking direction of the individual laminations 13.

The basic manufacturing process of Figs. 1 through 3 describes the essential characteristics of what is known as the flat-packet technique for producing stators 36 for electrical machines. Briefly, this flat-packet technique can be described by the following characteristics: An essentially striplike stator 10 is furnished, which optionally has a laminated construction. An at least one-piece stator winding 30 is placed in the slots 25 of the stator iron 10. In a following step, the stator iron 10 with the stator winding 30 is put into an annular-cylindrical shape.

Fig. 4 shows a detail of an elevation view of the end face of the stator iron 10, which is oriented in the direction of the cylinder axis or axial direction a. The circular-annular segment between two adjacent radially oriented center lines 40 of two immediately adjacent inner teeth 19 is assumed here to be the slot area A_{Fe}. The slot area A_{Fe} accordingly comprises the surface portions of two half-inner teeth 19 and the corresponding yoke face portion between the center lines 40. A slot area A_{Nut} is created from the contours of the corresponding yoke face and the

inner teeth 19 as well as by the circular boundary line between two tooth heads 50 of the inner teeth 19. Examinations of stators 30 made by the aforementioned flat-packet technique have demonstrated that a ratio A formed of the slot area A_{Nut} and the end face area A_{Fe} favorably amounts to between 0.4 and 0.8. It can thus be stated as a favorable combination of characteristics for a stator 36 that this stator 36 made by the flat-packet technique initially comprises a stator iron 10 and stator winding 30, and the stator iron 10 has a substantially annular-cylindrical shape and the stator iron 10 has an axial direction a, which is oriented in the direction of a cylinder axis, and the stator iron 10 has an end face, oriented in the direction of the cylinder axis, that has a slot area A_{Nut}, and a ratio A formed of the slot area A_{Nut} and the end face area A_{Fe} amounts to between 0.4 and 0.8.

In a further approximation, it has been found that the ratio A is even more favorable if it is between 0.4 and 0.7.

The end face area taken into account for the ratio A does not include the cross-sectional area A_{Za} that can be ascertained in the axial direction a and that is formed for instance by the corresponding cross-sectional area of two half-teeth 53 that on the outside are oriented radially outward. If the outer contour of the yoke 16 in the radial direction does not describe a circular line, then the smallest diameter that the outer contour of the stator iron describes in the region b_3 above the slot is used as the outer diameter for calculating the end face area A_{Fe}.

It has furthermore been found that the ratio A, depending on the number of teeth of the stator iron 10, can assume different ideal values. For instance, it has been found that stator irons 10 that have forty-eight inner teeth 19 favorably have a ratio A of between 0.45 and 0.7. It is clear that one of the forty-eight inner teeth 19 must be considered equivalent to two half-inner teeth 27.

In a second approximation, it has been found that stator irons 10 with forty-eight inner teeth 19 19 favorably assume a ratio A of between 0.45 and 0.6. For stator irons 10 with thirty-six inner teeth 19, a numerical range between 0.4 and 0.6 is considered a favorable ratio A.

In a second approximation, for a stator iron 10 with thirty-six inner teeth 19, a favorable ratio A is considered to be between 0.4 and 0.55.

In conjunction with Fig. 4, it will be explained how the slot area A_{Nut} is ascertained. In conjunction with Fig. 5, it will be explained how the cross-sectional area of the conductors 56 located in the slot 25 can be ascertained. Each conductor 56 has a conductor cross section A_L. The total of all the conductor cross sections in one slot 25 is thus the total of the individual conductor cross sections A_L, or in other words $A_{L,total}$. A slot fill factor F is defined here as the ratio of the cross-sectional area of all the conductors 56 in one slot 25 and the slot area A_{Nut}. For stator irons 10 or stators 36 with thirty-six slots 25 and thirty-six inner teeth 19, in a version for rotary current machines with six pole pairs, the stator current I_G has been ascertained as a function of the ratio A and the fill factor F. Fill factors F of 50%, 65% and 80% were examined here. It was ascertained that the highest generator current is attained for a fill factor F of 80%; see also Fig. 6a. Accordingly, for a fill factor F of 80%, the corresponding curve in Fig. 6a is marked F_{80}. The abscissa axis indicates the ratio A in a range between approximately 0.6 and 2.0, while the ordinate axis shows the ratio B of between 0.5 and 1.0. The ratio B is ascertained as a function of the current course for a fill factor F. For that purpose, in a corresponding electrical machine with a stator 10 and a slot fill factor F = 80%, the corresponding generator current or stator current has been ascertained. The maximum value of this current course is set to be equal to 100%, or in other words 1.0. Based on this maximum value, the curve course for a slot fill factor F_{80} was plotted. Analogously, the stator current for a slot fill factor F = 65% and a slot fill factor F = 50% was ascertained. The corresponding curves are designated as F_{65} and F_{50}, respectively. The corresponding curve courses were referred to the maximum value for the current for a slot fill factor F = 80%.

On the basis of these findings, for a stator made by the flat-packet technique with thirty-six slots 25 and thirty-six inner teeth 19 with six pole pairs, a ratio A of between 0.4 and 0.55 is preferred, while at the same time the slot fill factor should be between 50% and 80%.

Fig. 6b shows a graph, analogous to the graph of Fig. 6a, for a stator 36 with

forty-eight slots 25 and forty-eight inner teeth 19 with eight pole pairs for a corresponding rotary current machine. On the basis of the findings ascertained here, a combination in which the ratio A is between 0.45 and 0.6 and the fill factor F is between 50% and 80% is preferred.

In conjunction with Fig. 7, the important geometrical relationships for a slot 25 will now be described. The width b1 designates the opening width of the slot slit or slot 25 existing in the bent-round state. The slot 25 has a contour that is defined on the side toward the yoke by diametrically opposed tooth sides 59 and by a yoke contour 62. The tooth sides 59 in this exemplary embodiment are rounded at the transition from the tooth sides 59 to the yoke contour 62 by radii r_3. The term "toward the yoke" here means the region of the slot 25 that is located on the side of the slot 25 oriented toward the yoke 16. The term "toward the tooth head" means that the corresponding region of the slot 25 is located on the side of the slot 25 that is toward the tooth head 55 and thus faces away from the yoke 16. In the exemplary embodiment, the tooth sides 59 of an internal slot 25 have a maximum spacing from one another in the circumferential direction that is designated here by the symbol b_{z3}. Thus for a slot 25 which is rounded by radii in the region between the yoke 16 and the tooth 19, b_{z3} is composed of the spacing b_3 between the two center points of the radii and the two radii r_3 themselves, so that for b_{z3} the equation that results is $b_{z3} = b_3 + 2*r_3$. In the event that a slot 25 is not rounded by any radii at all but instead by ellipses, chamfers, or any angular transitions between the tooth side 59 and the yoke contour 62, b_{z3} should be the widest spacing, toward the yoke, between the two tooth sides 59.

The slot pitch $\tau 2$ is defined as the spacing between two tooth centers at the diameter of the spacing b_{z2}; the slot pitch $\tau 3$ is defined as the spacing between two tooth centers at the diameter of the spacing b_{z3}. The diameter d3 is the diameter at which the spacing b_{z3} is defined, and the diameter d2 is the diameter at which the spacing b_{z2} is defined. For the ratio of d3 to d2, a numerical range between 1.1 and 1.25 should apply.

Analogously, there is a contour, toward the tooth head, of the inner slot 25 that is defined by the diametrically opposed tooth sides 59 and tooth head contours

65. The tooth head contour 65, in this exemplary embodiment, begins at the transition from the rectilinear tooth sides 59 to the constriction, predetermined by radii r_2, of the slot slit or slot 25 in the direction radially inward. The width b_2 here designates the spacing of the center points of the radii r_2, so that the total of the center point spacing b_2 and the two radii r_2, adding up to b_{z2}, is the width, toward the tooth head, of the slot 25, or in other words the spacing of the tooth sides 59.

In the event that there is no unequivocal relationship, along the lines of the definitions given above, of the spacings b_{z2}b and b_{z3}, for instance if the tooth sides 59 bulge slightly, then the following further definition should apply for the aforementioned spacings b_{z2} and b_{z3}: Based on rounded tooth head contours 65, which means that the transition from the tooth widths 59 into the inner circumference of a stator iron 10 or of the stator 30 is completely rounded, under some circumstances it is not possible to state a radial height for the slot 25 unambiguously. As an aid in this situation, the radial spacing between the yoke contour 62, or its circular extension, and a center point of a tooth head should apply. The center points of the tooth head, or the spacing between two adjacent tooth head center points, furthermore defines the slot pitch τ. If this spacing is set at 100%, this means that the width, or spacing b_{z2}, beginning at the lowest point of the slot 25 or at the yoke 16 from which the inner teeth 19 extend, is ascertained as 90%, and the same is analogously true for the spacing b_{z3}, which is ascertained at a height of 8%.

In Fig. 8, a relationship between the stator current at engine idling (corresponding to a rotary speed of the generator rotor of approximately 1800 rpm) as a function of the ratios c2 and c3. c2 is the quotient of the slot width toward the tooth head, or spacing b_{z2}, and the slot pitch τ2 at the tooth; c3 is the ratio formed of the spacing b_{z3} toward the yoke and the slot pitch τ3 at the yoke. For a stator 36, it is provided that the ratio c2 and the ratio c3 amount to between 0.45 and 0.65.

Especially preferably, c2 amounts to between 0.50 and 0.60, and C3 amounts to between 0.47 and 0.6.

If the transitions between the tooth sides 59 and the yoke contour 62, and/or between the tooth sides 59 and the tooth head contour 65, are rounded, radii then r_1 and r_2 of between 0.3 and 2.0 mm are preferred.